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WATER QUALITY REQUIREMENTS FOR ATLANTIC SALMON

Joseph N. DeCola

Federal Water Quality Administration
Needham Heights, Massachusetts

August 1970

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Northeast Region
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I. INTRODUCTION

Acknowledgements

The New England Basins Office wishes to acknowledge the assistance of the United States Bureau of Sport Fisheries and Wildlife of Boston in the review of this report. Appreciation is also extended to Dr. Paul F. Elson and Dr. Richard L. Saunders of the St. Andrews Biological Station in New Brunswick, Canada, and to Mr. Alfred L. Meister of the Atlantic Sea Run Salmon Commission whose comments greatly aided the finalization of this report.

Background and Scope

Under Section 3(a) of the Federal Water Pollution Control Act, the Secretary of the Interior is directed to develop comprehensive programs for eliminating or reducing pollution of interstate waters and tributaries thereof considering the improvements which are necessary to conserve such waters for legitimate uses including propagation of fish and other aquatic life.

Section 3(b) of the Act states that in the survey or planning of any reservoir by the Corps of Engineers, Bureau of Reclamation, or any other Federal agency, consideration shall be given to inclusion of storage for regulation of streamflow for the purpose of water quality control. The need for and value of storage for this purpose shall be determined by these agencies with the advice of the Secretary.

In both the development of comprehensive water quality management programs and streamflow regulation systems for water quality control, the future potential uses of the waters and the associated levels of water quality must be recognized.

Under the provisions of the Anadromous and Great Lakes Fisheries Restoration Act of 1965, a cooperative fishery restoration program has been initiated for the Connecticut River Basin. A copy of the restoration agreement between the participating State and Federal fishery agencies is included in Appendix B. The objectives of this

program are to realize the full potential of the fishery resources of the River including both anadromous and resident species. Small runs of Atlantic Salmon (Salmo salar) have been restored in the Machias, Dennys, Pleasant, East Machias, Narraguagus and Sheepscot Rivers in Maine, and the possibility of restoring them in other New England rivers is being explored. From the standpoint of water quality, the salmon is one of the most sensitive species which is being considered under the restoration program. The water quality requirements for the Atlantic Salmon will, therefore, play a large role in the development of a water quality management program.

Objectives

The objective of this report is to present a summary of the results of research and investigations on the water quality requirements for Atlantic Salmon. It should be noted, however, that the information available on water quality requirements for Atlantic Salmon is limited. Although adequate information exists on oxygen and temperature requirements at the egg stages, few sources deal with water quality requirements during other fresh water stages.* Much of the recorded experimentation during fresh water stages examines only lethal or near lethal temperatures and dissolved oxygen concentrations which barely permit salmon survival. Near lethal levels of water quality are totally inadequate for feeding activities, growth, reproduction and normal

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* The life cycle of the Atlantic Salmon is contained in Appendix A

swimming performance and, thus, cannot be used as water quality requirements. Some excellent information exists on the requirements of Pacific Salmon during fresh water stages. This information can supplement the available data on Atlantic Salmon and can aid in establishing tentative water quality requirements until further research is carried out.

II. SUMMARY

Concentrations of dissolved oxygen, carbon dioxide, toxic pollutants, together with temperature and pH levels greatly affect productivity of fish. Near air-saturated dissolved oxygen concentration with maximum temperatures not exceeding 19°C is optimum for growth and activity of Atlantic Salmon. Extended exposure of Atlantic Salmon to dissolved oxygen concentrations below 5.0 mg/l, temperatures above 20°C, or various toxicants causes their reduction or elimination from the environment.

Dissolved oxygen requirements for Atlantic Salmon are highest during hatching and at other stages during periods of high activity, such as swimming against currents and foraging for food. The oxygen required to sustain activity varies with water temperature and also with apparent water velocity during embryonic stages. As temperature rises, metabolic activity rises causing an increase in oxygen requirements for all stages. During embryonic development, apparent water velocities of 100 cm/hr and above are necessary to insure delivery of oxygen to eggs and alevins which are buried within the gravel of the streambed. Spawning areas should remain free of silt since sedimentation causes reduction in apparent water velocity.

During embryonic development of salmonoids, sustained dissolved oxygen concentrations below 4 or 5 mg/l or low apparent water velocities cause retarded development, hatching of weak sac-fry, malformity, and mortality. During other stages, concentrations of dissolved oxygen below

6 mg/l seriously restrict swimming ability and reduce growth. Although juvenile Atlantic Salmon are able to exist in the laboratory at dissolved oxygen concentrations as low as 3 mg/l at temperatures of 20°C, such low concentrations are inadequate in nature.

For good development and hatching of Atlantic Salmon, intragravel dissolved oxygen concentrations should be at least 7 mg/l with apparent water velocities not less than 100 cm/hr. If apparent water velocity is low, then an intragravel dissolved oxygen concentration at or near air saturation is necessary for normal development.

At parr, smolt and adult stages, normal productivity requires dissolved oxygen concentrations of 6 mg/l and above. Minimum dissolved oxygen levels may range between 5 and 6 mg/l for short periods. For those portions of the river used during migration, sustained dissolved oxygen concentrations should be above 5 mg/l. Dissolved oxygen concentrations below 5 mg/l could produce a block to migrating salmon.

Water temperatures are extremely important to the production of healthy Atlantic Salmon. Temperature greatly affects metabolism and generally a 10°C rise in temperature doubles the oxygen consumption of salmonoids. Growth, activity and migrations of Atlantic Salmon are also largely controlled by ambient water temperatures which must undergo seasonal cooling before spawning and normal incubation of eggs will occur. For example, temperatures in excess of about 12°C preclude maturation of sexual products in adults while spawning occurs at temperatures of about 5.6°C to 4.4°C. Normal growth and development of eggs does

not proceed at temperatures above 9°C. At 12°C, at least 50% mortality of eggs can be expected, and hatching alevins will be weak or deformed. Subsequent to hatching in the spring, however, warmer temperatures are required for optimum growth of the young salmon. Optimum temperatures for best food consumption and growth rate of salmon parr are in a range of about 15°C to 19°C. The optimum temperature for post-smolt salmon has been recorded as 15°C with salinities of about 10°/oo. Although thermal optima for the growth of adult Atlantic Salmon are not available, mature salmon apparently require much cooler water than juveniles. Adult salmon in Greenland waters have been found feeding and growing at temperatures as low as 2°C--a temperature known to inhibit feeding and growth of parr in rivers. Why adult salmon seem to prefer cooler temperatures is not known, but is probably related to physiological changes that occur during and after smoltification, as well as acclimation of adults to cooler sea temperatures.

Atlantic Salmon do not tolerate high temperatures, and excessive stress or mortality of salmon occurs as temperatures exceed 27°C - 29°C. In addition to dissolved oxygen concentrations, principal among the factors determining the tolerance of Atlantic Salmon to thermal elevations is the prior acclimation temperature. Lowering or raising the acclimation temperature causes a corresponding reduction or elevation in the upper limit of thermal tolerance. Salmon that are acclimated to low temperatures are particularly susceptible to death from thermal elevations. Sudden 10°C - 15°C temperature rises will cause serious adverse effects. In the laboratory, juvenile Atlantic Salmon

acclimated to 20°C were just able to tolerate temperatures of 27.5°C. At an acclimation temperature of 13°C, however, a 14.5°C rise to the same temperature of 27.5°C produces 50 percent mortality in just under 2½ hours for the same age salmon.

In nature Atlantic Salmon parr undergo a continual year-round process of acclimation to changing water temperatures, while adult salmon returning from the sea to spawn, may not fully acclimate to the warmer fresh water, and thus, would be more susceptible to death from high temperatures. Mortality of adult Atlantic Salmon from heatstroke can be expected when temperatures exceed 29°C - 30°C.

Temperatures do not have to reach lethal levels to cause undesirable effects upon salmon populations. Migrations of smolts will cease when water temperatures exceed 10°C, and adults may not enter Maine rivers when temperatures exceed 23°C. Temperatures above 20°C, however, reduce activity of adult salmon and are not conducive to fishing. When Atlantic Salmon are subjected to such high temperatures, they will require about 10 days at reduced water temperatures before they will be active enough to respond to angling. In addition to these effects, temperatures in a range of about 20°C to 27°C, although not directly lethal to Atlantic Salmon, greatly increase oxygen requirements, favor the growth of undesirable disease organisms which are rapidly lethal to salmon at high temperatures, and enhance the development of more thermal tolerant fish that replace salmon through predation and competition. Maximum temperatures for rearing of juveniles and migration of adult Atlantic Salmon should not exceed 20°C.

During fresh water stages, Atlantic Salmon in Maine are typically found in very soft waters with a total alkalinity less than 20 ppm and with a pH ranging from 5-7. In other areas, Atlantic Salmon have been found in alkaline waters with a pH above 8. Most productive populations of fish are found in waters where the pH ranges from 6.5 to 8.5.

Salmonoids are tolerant of relatively high carbon dioxide concentration at all stages in development. However, since carbon dioxide causes an increase in the dissolved oxygen requirements, carbon dioxide concentrations should not exceed 25 mg/l.

Threshold or incipient lethal concentrations of copper and zinc for Atlantic Salmon parr have been recorded as 0.032 mg/l of copper and 0.42 mg/l of zinc or a mixture containing half of these concentrations in soft water (14 mg/l as $CaCo_3$). Avoidance by adult salmon in nature to copper and zinc pollution below lethal levels has been documented by Canadian biologists. Utilizing the concept of toxic units to express pollution levels (toxic unit = concentration of substance actually found ÷ the incipient lethal concentration) investigators have shown that adult salmon migrating to spawning areas may be completely blocked by a level of 0.8 toxic unit, while significant avoidance reactions of salmon occur at about 0.35 to 0.43 toxic units of $Cu^{2+} + Zn^{2+}$. In streams supporting runs of Atlantic Salmon, levels of zinc and copper pollution should be minimized as much as possible and levels not exceeding 0.25 to 0.30 toxic units should not cause avoidance reactions in salmon, providing other water quality is favorable.

Information concerning the effect of toxicants upon Atlantic Salmon is limited. Based upon available data, the National Technical Advisory Committee (4) has recommended the following: Concentrations of materials that are nonpersistent (half life of less than 96 hours) or have non-cumulative effects after mixing with receiving waters should not exceed 1/10 of the 96-hour TLm value at any time or place. The 24-hour average of the concentration of such substances should not exceed 1/20 of the TLm value after mixing. For other toxicants, concentrations should not exceed 1/20 of the 96-hour TLm value at any time or place and the 24-hour average of the concentrations of these materials should not exceed 1/100 of the 96-hour TLm.

Because of adverse existing water quality, the TLm value of heavy metals, pesticides and other toxicants can be considerably lower than the estimated or anticipated concentration. Stream temperatures above 20°C and dissolved oxygen concentrations below 4 or 5 mg/l greatly increase the susceptibility of salmon to industrial and agricultural toxicants. For this reason, existing guidelines on safe levels of toxicants may be inadequate in some cases.

Table 4 in this paper, McKee & Wolf's Water Quality Criteria (42) and the Report of the Committee on Water Quality Criteria (4) contain some good information on TLm values and the recommendations on determining safe levels may be employed to determine tentative guidelines for Atlantic Salmon until further research is undertaken.

III. DISSOLVED OXYGEN REQUIREMENTS

Introduction

Dissolved oxygen requirements of Atlantic Salmon vary with the different stages of their life cycle. Dissolved oxygen concentrations during embryonic stages should be near saturation. Similarly high concentrations of oxygen are necessary at the parr and adult stages during periods of high activation, such as swimming against currents, and foraging for food. Low concentrations of oxygen such as 3 or 4 mg/l are inadequate since they cause serious reduction in the activity and growth rate of salmon.

Water velocity and temperature also influence the dissolved oxygen requirements for salmon. During the embryonic stage, a high apparent water velocity* is necessary to carry the oxygen supply to the developing embryos which lie in the interstices of gravel beds (redds) at an average depth of ten inches. If the apparent water velocity is insufficient, few developing embryos will receive enough oxygen for normal metabolism. Temperature greatly affects the oxygen requirement during every stage of the fish's life. Oxygen demand can be increased or decreased by corresponding changes in water temperatures. Generally, an increase in water temperature will raise the amount of oxygen that is necessary to maintain proper metabolism and activity of salmon.

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* The apparent water velocity is an estimate of the true velocity of the water flowing through the spawning bed (redd) and is calculated by dividing volume discharge per unit time by the cross-sectional area.

Oxygen Requirements During Embryonic Stages

Laboratory studies upon developing Atlantic Salmon eggs demonstrate that oxygen demand increases greatly with age. While working with Atlantic Salmon embryos at constant temperature, Hayes (1;2) found that respiratory rates were lowest just after fertilization and highest just prior to hatching. Other experimenters, working with Pacific Salmon embryos, also found that increased development is directly related to an increase in oxygen demand (3). Thus, for salmon embryos, there is a continual increase in oxygen demand that culminates near hatching.

Experimenters have determined critical dissolved oxygen concentrations at various incubating temperatures just prior to hatching which is the most crucial period for the developing eggs. Below a critical dissolved oxygen concentration normal metabolic activity of Atlantic Salmon will be restricted. As shown in Figure 1, a linear relationship is established when incubating temperatures and critical dissolved oxygen concentrations are plotted just prior to the hatching of Atlantic Salmon eggs. At a temperature of 17°C, which is substantially above normal incubation temperature, Atlantic Salmon eggs just prior to hatching require minimum dissolved oxygen concentrations of 8.7 mg/l to maintain respiratory demands. At 9°C, normal development of Atlantic Salmon eggs just prior to hatching is sustained by dissolved oxygen concentrations of about 7 mg/l. At a temperature of 6°C, the critical dissolved oxygen concentration is 6 mg/l.

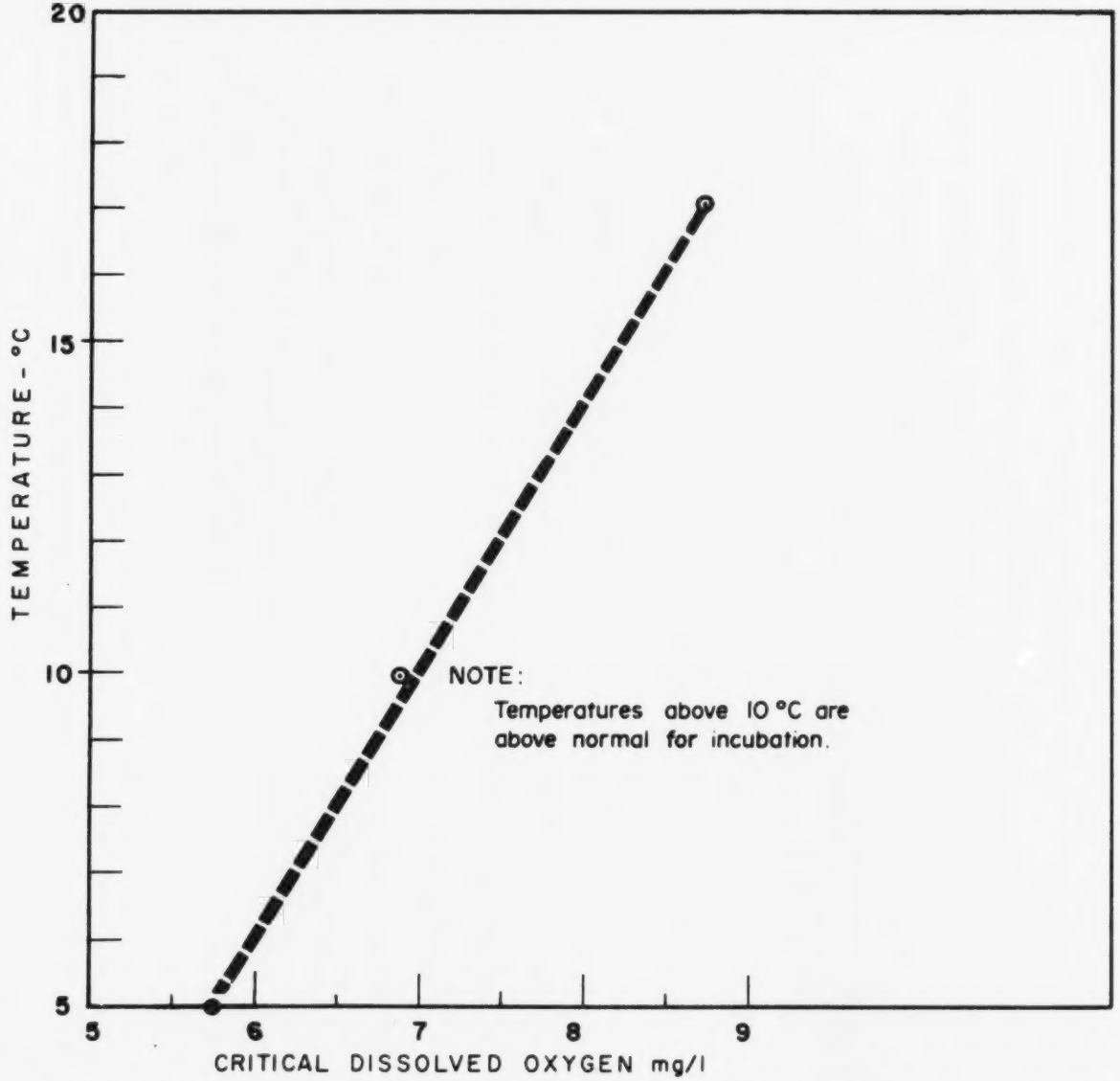

FIGURE 1. Critical dissolved oxygen levels for Atlantic Salmon eggs just prior to hatching at various temperatures. Data from Hayes (1;2) and Lindroth (5).

The National Technical Advisory Committee (4) recommends an absolute minimum dissolved oxygen concentration of 7 mg/l in spawning areas of salmon and trout. This recommendation is quite consistent with the data presented in Figure 1, since embryonic development of Atlantic Salmon occurs in water temperature up to about 9°C.

It is important to realize that near saturated concentrations of dissolved oxygen in the water directly above the stream bed may be required to sustain 7 mg/l of dissolved oxygen within the redds. Ecological factors such as periphytic vegetation, slime growth, siltation, and the invertebrate population may have an oxygen demand that could seriously deplete the oxygen supply of the percolating water before it reaches the incubating eggs. Oxygen depletion is especially high in polluted areas that contain large numbers of invertebrates and oxygen demanding benthic deposits.

Salmon eggs buried within the redds are entirely dependent upon the sub-surface movement of water to supply them with the oxygen necessary for survival and growth. High apparent water velocities are necessary to carry away metabolic waste products in addition to delivering oxygen to salmonoid embryos. Low apparent water velocities may result in a build-up of waste materials causing a lethal micro-environment. Wickett (6) demonstrated that even air-saturated water would not sustain embryonic life of Pacific Salmon if the apparent water velocity were below .05 cm/hr. Peters' (7) experiments (Table 1) with rainbow trout embryos support Wickett's conclusion that mortality

TABLE I. Trout egg mortality compared with intragravel oxygen concentrations and intragravel apparent velocities at winter incubation temperatures. Taken from Peters (7).

Station Number	Mortality, %	Oxygen Concentration, PPM		Apparent velocity, cm/hr	
		Average	Range	Average	Range
I	5	7.8	7.4 to 8.1	82	75 to 90
II	39	7.8	7.3 to 8.1	61	55 to 85
III	90	7.6	7.1 to 8.1	43	15 to 85
IV	100	7.3	6.4 to 8.1	21	5 to 90
V	100	7.1	6.4 to 7.9	23	10 to 85

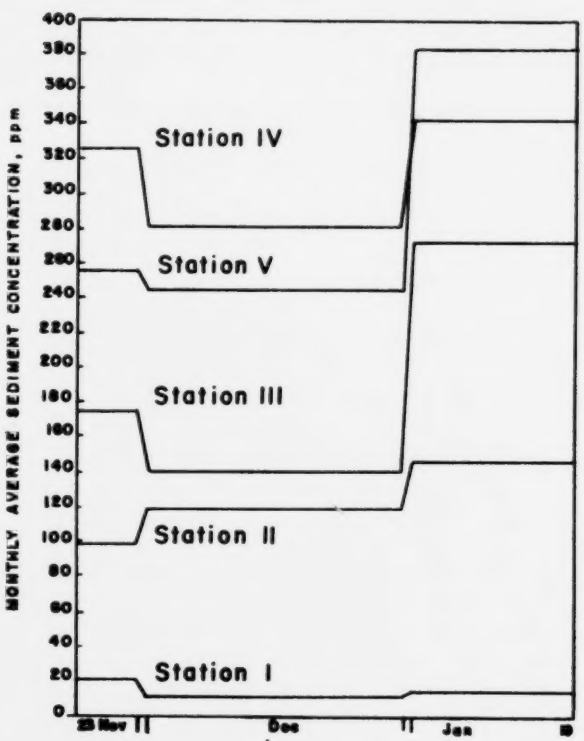

FIGURE 2. Monthly average sediment concentrations from five sampling stations in Bluewater Creek from November, 1961 through January 1962. Taken from Peters (7).

of salmonoid embryos is affected by the apparent water velocity since rainbow trout eggs, like salmon, incubate in redds. Coble's (8) experiments have also demonstrated that mortality rates of salmonoid embryos are increased with low apparent water velocities.

Changes in stream bottom composition from siltation can restrict the percolation rate of water through the redds. If the stream bed is heavily silted, the apparent water velocity is so drastically reduced that even air-saturated water would not produce successful hatching of salmonoids. Table 1 shows the effect of apparent water velocity upon mortality of rainbow trout eggs placed seven inches deep within gravel redds at Bluewater Creek, Montana during winter conditions. The concentrations of dissolved oxygen within the redds (the intragravel dissolved oxygen concentrations) during the experiment were continually above 6 mg/l. Based on data from Table 1 and Figure 2, a decrease in apparent water velocity at each station is associated with a corresponding increase in sedimentation and trout mortality. At Station III (Table 1) when the average apparent velocity is 43 cm/hr, a 90 percent mortality occurs; this velocity is insufficient to meet the oxygen demands of the developing trout embryos. At Station I, where sedimentation is minimal (Figure 2) and where the average apparent velocity is 82 cm/hr (Table 1), the mortality is estimated to be only five percent. Therefore, high sedimentation of the spawning beds reduces the apparent water velocity and decreases the supply of oxygen to the developing embryos which results in increased mortality. Low apparent water velocities could also cause

covering of the eggs by suspended sediment resulting in oxygen deficiency.

Based on the observations of Wickett (6) and Peters (7), assuming sufficient intragravel dissolved oxygen concentrations (see Figure 1), apparent water velocities greater than 100 cm/hr may result in the successful hatching of healthy salmonoid sac-fry.

Laboratory experiments on salmonoid embryos have demonstrated that the usual result of oxygen deficiency during embryonic stages is a significant reduction of successfully hatching sac-fry. In flowing water experiments with coho salmon embryos, Warren (9) demonstrated that dissolved oxygen concentrations even as high as 5 mg/l at a water temperature of 12.5°C did not produce satisfactory hatching. Garside (10) reported that extended exposure of lake trout embryos to an average oxygen concentration of 4.2 mg/l at a water temperature of 10°C resulted in high or total embryo mortality. Alderice (3) recorded that seven-day exposure of chum salmon embryos at various developmental stages at a constant temperature of 10°C and dissolved oxygen concentrations less than 2 mg/l resulted in three prominent responses: retarded embryonic development, deformed sac-fry, and mortality. The apparent water velocity for these experiments was 82 cm/hr. The median lethal dissolved oxygen concentration was estimated to be 1.2 mg/l at hatching. Silver (11) noted that all the embryos of chum salmon and steelhead trout died after exposure to a temperature of 11°C in flowing water at a dissolved oxygen

concentration of 1.6 mg/l. In another experiment, Silver raised the dissolved oxygen concentration to 2.15 mg/l and obtained a successful hatching of sac-fry. However, the sac-fry that hatched were exceptionally weak and small. Such individuals would not be strong enough to survive emergence from the overlying gravel in nature. Thus, low concentrations of dissolved oxygen during embryonic development for salmonoid species result in retarded development, hatching of weak and small sac-fry, malformity, and mortality.

Oxygen Requirements During Juvenile and Adult Stages

The concentration of dissolved oxygen that is required by free-swimming salmon is largely dependent upon water temperature and activity of the fish. Active salmonoids consume from three to five times the amount of oxygen as resting fish, while a temperature increase of 10°C generally doubles oxygen consumption.

Fry (12a) demonstrated the relationship of oxygen uptake and temperature for three species of yearling trout, genus Salmo, in both active and resting conditions (see Figure 3) The oxygen consumption for either Salmo gairdneri or Salmo kamloops ranged approximately from 60 cc/kg/hr at 10°C to 140 cc/kg/hr at 20°C when resting. For the same fish during periods of activity, the oxygen consumption ranged from 235 cc/kg/hr at 10°C to about 390 cc/kg/hr at 20°C. When Fry tested the oxygen consumption rate for Salmo fario, he found that at 10°C and 20°C for resting fish the consumption was 60 cc/kg/hr and 135 cc/kg/hr respectively. The active respiratory rate at 10°C and

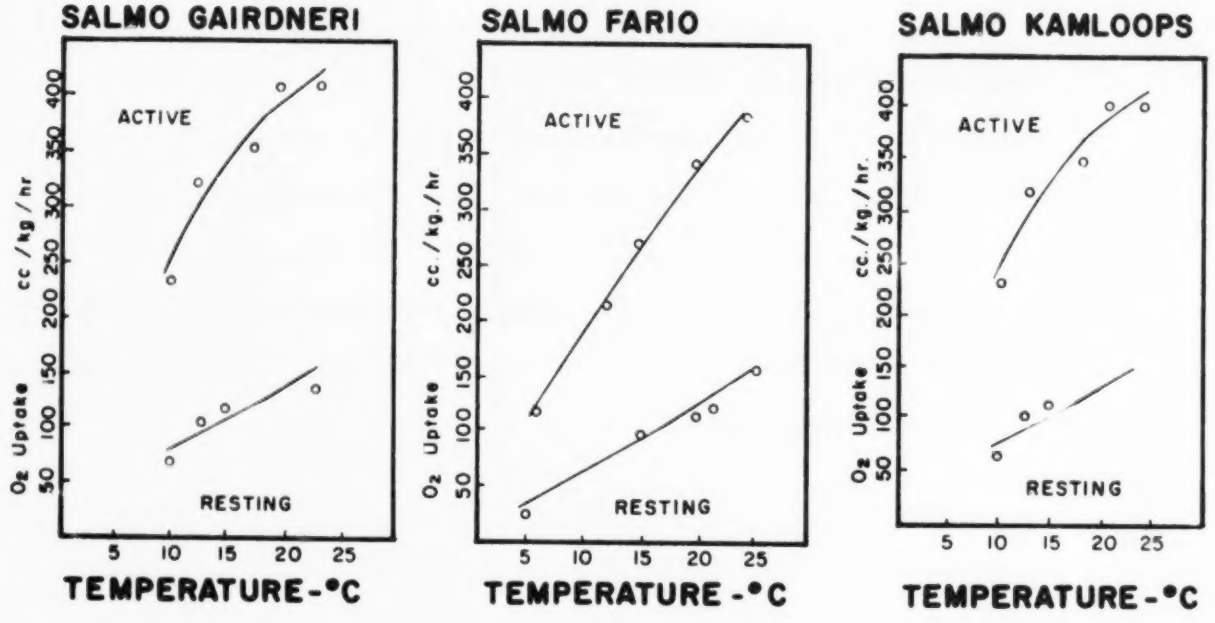

FIGURE 3. Relation between oxygen uptake and temperature. Taken from Fry (12a).

$20^{o}C$ was about 200 cc/kg/hr and 350 cc/kg/hr respectively. Several other experimenters have also demonstrated that the oxygen required by salmonoids is affected by temperature and activity (12b; 13; 14; 15; 16).

The activity of salmon can be seriously limited in oxygen deficient conditions. Table 2 gives the dissolved oxygen concentrations below which the activity of various fish, including certain salmonoids, begins to decline. To be successful in a natural environment, salmon must be capable of resisting high currents, escaping from predators, and foraging for food. Such activities necessitate a high oxygen consumption that can be maintained only by high concentrations of ambient dissolved oxygen. Low concentrations of dissolved oxygen seriously restrict activity which may be measured by laboratory experiments.

Davis (17) demonstrated that reduction of dissolved oxygen causes a marked reduction in the swimming speed of juvenile coho and chinook salmon. Oxygen concentration from saturation to levels of 7, 6, 5, 4, and 3 mg/l reduced the maximum sustained swimming speeds of juvenile coho salmon by about 5, 8, 13, 20, and 30 percent respectively. The corresponding percentage reductions of the swimming speed of chinook salmon were somewhat greater and averaged 10, 14, 20, 27, and 33 percent respectively. Thus, activity as measured by swimming performance is considerably restricted at low dissolved oxygen concentrations.

TABLE 2

OXYGEN CONCENTRATIONS BELOW WHICH THE ACTIVITY

OF THE FISH NAMED BEGINS TO BE RESTRICTED

Taken from Jones (16)

KIND	OXYGEN CONCENTRATION	Temp. ^{o}C
Goldfish	2.5 p.p.m.	20
Goldeye	9.0 p.p.m.	10
"	11.0 p.p.m.	15
Perch	7.0 p.p.m.	20
Speckled trout	6-7 p.p.m.	5
" "	6-7 p.p.m	10
" "	9.0 p.p.m	20
Lake trout (1 yr)....	abt. 2/3 saturation	9.5-18
" " (2 yr)....	abt. 3/4 saturation	9.5-18

Experiments by Davison (18) with juvenile coho salmon show that growth rate and conversion of food to body tissues are significantly reduced at low levels of dissolved oxygen. After five tests at oxygen concentrations of 4, 5, 6 and 8 mg/l in 20°C water, the mean weight gains after approximately twenty-four days were recorded as 56, 68, 85 and 92 percent respectively. The increase in weight of each fish per gram of food consumed averaged 168, 188, 216, and 220 mgms, respectively. Warren (9) obtained results similar to Davison's and also reported that high oxygen concentrations produce the best growth rates and efficiency in conversion of food to body weight. The experiments of Davison (18) and Davis (17) indicate that significant reduction in swimming speed and in growth rate of salmon occurs as dissolved oxygen concentrations are reduced below 6 mg/l.

The dissolved oxygen concentration at which the activity of free-swimming salmon is completely restricted and is only capable of existence is referred to as the limiting level, below which mortality will occur. Limiting or survival concentrations of oxygen have been determined experimentally for some free-swimming salmonoids at various temperatures (Table 3). The limiting oxygen concentration for Atlantic Salmon fingerlings is 1.51 mg/l at 15°C and 2.85 mg/l at 25°C. For yearling Atlantic Salmon, limiting dissolved oxygen concentrations are 1.89 mg/l and 2.78 mg/l at 16°C and 25°C, respectively. For parr, the limiting oxygen concentrations at 10°C and 20°C are 2.15 mg/l and 2.90 mg/l, respectively. Although these data demonstrate temperature

TABLE 3

LIMITING OR SURVIVAL CONCENTRATIONS OF OXYGEN
FOR
SALMON AT VARIOUS TEMPERATURES

Species	Dissolved Oxygen mg/l	Temperature-^{o}C	State	Reference
Atlantic Salmon	1.51	15	Fingerling	(19)
"	2.85	25	"	(19)
"	1.89	16.0	Yearling	(19)
"	2.78	25.0	"	(19)
"	2.15	10	Parr	(5)
"	2.90	20	"	(5)
Sockeye Salmon	2.4	21	Adult	(20)
Chinook Salmon	2.3-2.7	21-23	"	(20)
Pink Salmon	1.99	17	"	(19)
"	3.36	25	"	(19)
Coho (Silver) Salmon	1.2-1.24	12.1-12.7	Fry	(20)
"	1.5-1.6	16	"	(18)
"	1.65	20	"	(18)
"	1.80	22	"	(18)
"	2.13*	23.5	"	(18)

* Concentration represents mean of test dissolved oxygen which ranged from 2.05 - 2.2 mg/l; only 97 percent survival recorded in this range.

effects on limiting oxygen concentrations, other variables such as growth, swimming, and normal overall activity as they apply to the natural environment are excluded. In nature, oxygen concentrations adequate to maintain productive levels of growth and activity are considerably higher than near lethal oxygen concentrations as determined by laboratory analyses. This factor is significant in evaluating the data presented in Table 3. Recommended minimum dissolved oxygen requirements for salmon in a natural environment should be 2-3.5 mg/l above the concentrations indicated.

Dissolved oxygen concentrations which are necessary for salmonoid fish to maintain healthy populations are high, particularly near spawning areas. Ellis (21) demonstrated by field observation that streams which produce a good fish population do not have dissolved oxygen concentrations below 5 mg/l. Tarzwell (22) noted that trout and salmon are not usually found in waters where minimum dissolved oxygen concentrations are less than 4-5 mg/l. Havey (23) recorded that Atlantic Salmon of the Union River in Maine maintain good populations when water temperatures are below 21.1^{o}C and when dissolved oxygen concentrations are 5 mg/l and above. The National Technical Advisory Committee (4) recommends that for good growth and general well-being of trout and salmon, dissolved oxygen concentrations should not be below 6 mg/l, but in extreme cases may range between 6 and 5 mg/l for short periods provided that other water quality is favorable. The Committee also indicates that in streams which serve as migratory routes only, dissolved

oxygen concentrations may be as low as 5 mg/l for periods up to six hours, but should never be below 4 mg/l at any time or place. It is important to realize that sustained concentrations of oxygen below 5 mg/l would be inadequate for Atlantic Salmon and could cause a block to migration.

IV. TEMPERATURE REQUIREMENTS

Introduction

Atlantic Salmon cannot tolerate very high temperature elevations. For example, temperatures of 27° to 28°C cause 50 percent mortality of Atlantic Salmon fingerlings in under five hours. Thermal requirements are especially exacting at early embryonic and larval stages during which time tissue and organs are not yet fully developed. With an increase in age, however, Atlantic Salmon are capable of tolerating higher temperatures (24). Thermal tolerance refers to a temperature zone in which existence is possible for extended periods and in which death is not due solely to temperature changes. The upper limit of the thermal tolerant zone is defined by an incipient lethal temperature, beyond which mortality occurs (25; 26).

Thermal tolerance of fish is particularly affected by acclimating temperature, which is that temperature to which fish are physiologically adjusted. In nature, acclimation is a continual year round process. For every acclimating temperature, there is a corresponding lethal temperature defined as that temperature at which 50 percent of a population will die (25; 26). A rise in acclimating temperature will produce a corresponding elevation in the lethal temperature until a point is reached at which the acclimating temperature reaches the lethal temperature. This point is termed the ultimate upper lethal temperature (16; 26).

Within the thermal tolerant zone, there is a preferred temperature which is physiologically suited to the salmon and which provides desirable activity and growth. The preferred temperature is affected by the acclimation temperature and an increase in acclimation temperature will effect an increase in the preferred temperature (12a; 26; 27, 28).

Temperature also governs metabolism and thus affects oxygen consumption and growth rates. Temperature controls activity and movement in salmon populations. Temperature can also favor the growth and reproduction of undesirable species which grow at the expense of the salmon population.

Temperature Requirements During Embryonic Stages

Incubating temperatures of 0.5°C to 7.2°C apparently do not affect mortality in Atlantic Salmon embryos (29; 30). In air-saturation, flowing water, continued exposure of Atlantic Salmon eggs and sac-fry in the hatchery to temperatures at or near 10°C caused excessive mortality (29). Markus (31) found that an incubating temperature of 12.2°C in air-saturated and flowing water caused approximately 50 percent mortality of 450,000 hatchery-reared Atlantic Salmon eggs. Most of the hatching sac-fry were either deformed or very weak. In most cases, hatching of Atlantic Salmon eggs will be unproductive when incubation temperatures exceed 9°C.

Range of thermal tolerance increases with age for Atlantic Salmon. Bishai (32) demonstrated that 50 percent mortality of Atlantic Salmon

alevins (sac-fry) reared in well-oxygenated water at 5° to 6°C occurred after three days when water temperatures were raised to 24°C in six hours. At a test temperature of 20°C, which is lethal for eggs, salmon alevins did not die, nor were there any signs of distress.

Temperature Requirements During Juvenile and Adult Stages

Markus (31) found that the best growth rates for hatchery reared Atlantic Salmon occurred in a temperature ranging from 15.6°C to 18.3°C. Although acclimation affects the preferred temperature, several authors indicate a final temperature preferendum exists which fish eventually select in a temperature gradient regardless of prior acclimation (26; 33). Javaid (34) working with 3.8 to 7.6 cm. underyearling Atlantic Salmon in various temperature gradients, found that at an acclimation temperature of 15°C and 20°C the juvenile fish initially selected temperatures of 15.7°C and 18.2°C respectively, but had a final preferendum of 17°C. It is also interesting to note that when Elson (34) subjected salmon parr to an electrical stimulus, the greatest response occurred at a temperature of 15°C. Optimum temperatures for normal growth of juvenile Atlantic Salmon lie in a range of about 15°C to 19°C.

Adult Atlantic Salmon appear to have optimum temperatures somewhat lower than those for juveniles. Ferguson (27) reported that landlocked salmon, Salmo salar sebago (exact age unknown) were found living in an area where the temperature ranged from 13.5°C to 16.2°C. Saunders and Henderson (47) in a laboratory experiment found that a temperature around 15°C and a salinity near the isosmotic level

(ca. 10°/oo) gave better food consumption and growth in post-smolt salmon than temperatures of 10°C or 18°C or salinities higher or lower than isosmoticity.

Saunders also pointed out an observation of Elson who noted that when parr in the Pollett River in New Brunswick had stopped growing as shown by their scales when water temperatures fell below 4°C, salmon taken in Greenland waters at 2° - 4°C were still active and had not yet formed winter bands on their scales. Apparently adult salmon are capable of growth at temperatures far below what is considered optimum for parr in fresh water, and obviously are physiologically suited to much colder waters than are pre-smolt salmon.

Excessively high temperatures cause stress in young salmon and in time result in mortality. Elson* indicates that as temperatures rise much above 27°C or 28°C, salmon parr may desert their usual homes and drift downstream; in doing so they may accumulate in cooler areas associated with inflowing springs and brooks. Figure 4 records the amount of time involved for a 50 percent mortality of fingerling Atlantic Salmon acclimated to various temperatures to occur. The short horizontal lines in Figure 4 indicate the incipient lethal temperature which denotes the boundary of the zone of tolerance (12a; 12b). At an acclimation temperature of 20°C, 50 percent mortality of the Atlantic Salmon occurred within six hours at 28°C and within

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* Elson, P. F., Biological Station, St. Andrews, New Brunswick. (Personal Communication)

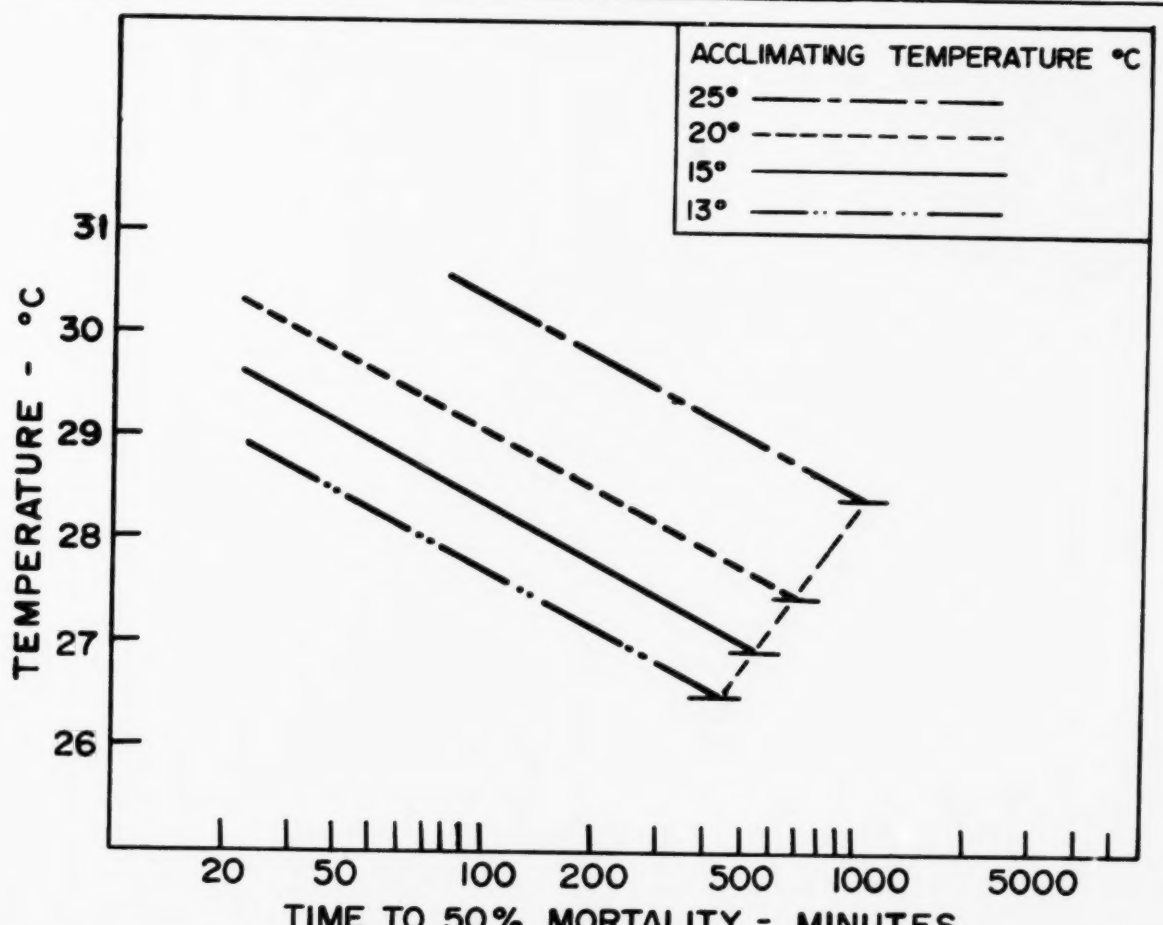

FIGURE 4 - Median resistance times for fingerling Atlantic salmon acclimated to various temperatures. Short horizontal lines indicate incipient lethal temperatures. **Taken from Fry (12a)**

one hour at 29.6°C. At an acclimation temperature of 13°C, 50 percent mortality of the salmon fingerlings occurred within six hours at 26.7°C and within one hour at 28.3°C. These data indicate that mortality of Atlantic Salmon occurs at 27-28°C in just a few hours, the exact time to mortality varying with the acclimation temperature.

Temperature is an important factor in the migration of salmon. Meister* of the Atlantic Salmon Sea Run Commission indicated that temperatures above 10°C will halt the migration of Atlantic Salmon smolts while temperatures of 12°C will preclude maturation of sexual products in adults. At 23°C, Maine salmon will not enter rivers, although some movement occurs with fish in the rivers prior to the advent of the high temperature (Meister). Meister and Elson both agree that temperatures above 20°C severely restrict success in fishing for adult salmon, and necessitate approximately ten days of reduced water temperatures before the fish will again respond to angling. Apparently, activity of migrating adult salmon can be severely reduced at temperatures above 20°C.

The loss of activity at temperatures of 20°C to 23°C is in part a result of acclimation. Adult Atlantic Salmon returning from the cold sea to fresh water streams may not remain in estuary areas long enough for them to become acclimated to the warmer brackish and fresh water. Such salmon would be vulnerable to high thermal elevations. Huntsman (35) found that adult salmon returning from the sea to

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*Meister, A., Atlantic Sea Run Commission, University of Maine, Orono, Maine. (Personal Communication)

Canadian streams and not fully acclimated to river temperatures died at 29°C to 29.5°C in a few hours, while those salmon already in the river prior to the development of lethal temperatures died at 30.5°C.

Stream temperatures do not have to attain lethal levels to cause undesirable effects for salmon. Sustained temperatures in a range of 20°C to 27°C, although probably not directly lethal in themselves, favor the reproduction and survival of more thermal tolerant species that replace salmon through competition and predation. Temperatures above 20°C also enhance the growth of bacteria and other disease organisms that can be lethal to salmon. Elson (see note, Page 29) indicates that in one Canadian stream under study during two recent years, serious bacterial epidemics occurred during the warm, low water of summer. Pippy and Hare (48) pointed out that sustained high temperatures in a range of about 20°C to 28°C apparently contributed to mortality of salmon from bacterial diseases. In addition to these effects, temperature elevations cause an increase in oxygen demand (see Figure 3) while at the same time lower the amount of oxygen dissolved in water.

For good growth and migration of salmonoids, the National Technical Advisory Committee (4) recommends that temperatures should not exceed a maximum of 20°C. This temperature maxima is consistent with the information gathered upon Atlantic Salmon.

V. OTHER ENVIRONMENTAL FACTORS

pH

The term pH designates the logarithm (Base 10) of the reciprocal of the hydrogen ion concentration. For example, if the hydrogen ion concentration designated $H^+ = 10^{-7}$ moles per liter, then the pH would equal 7. The National Technical Advisory Committee (4) indicates that in a pH range above 6, acids which dissociate to a high degree do not appear to be toxic to fresh-water fish; below a pH of 9, alkalies that dissociate to a large degree are also not considered hazardous to fish. In the same pH range from 6-9, however, weakly dissociated acids and alkalies, if present in sufficient quantity, are toxic and can be lethal to fresh-water fish (36). Such substances, however, do not occur naturally in lethal concentrations and are associated with industrial waste effluents. Thus, even at neutral or near neutral pH, waters may contain acids and bases which could be toxic to fish.

Fresh-water fish grow more rapidly and are more productive in water which is slightly alkaline than water which is strongly acidic. Good well-rounded populations of fish are found normally in waters where the pH ranges from 6.5 to 8.5 (21; 37); however in Maine, Atlantic Salmon are typically found in fresh water where the pH ranges from 5-7.

Carbon Dioxide

Salmonoids are tolerant of high concentrations of carbon dioxide.

Alderice (38) found that chum salmon eggs were relatively resistant to high levels of carbon dioxide under low-dissolved oxygen concentrations. He recorded a 50 percent mortality when the concentration or carbon dioxide was raised to 90 mg/l. Concentrations of 40 mg/l of carbon dioxide had little effect upon juvenile coho salmon (16). However, increases in the carbon dioxide concentrations cause an increase in the dissolved oxygen requirements of salmonoids (16;38; 39). Carbon dioxide concentrations not exceeding 25 mg/l are recommended by the National Technical Advisory Committee (4).

Threshold Concentrations of Copper and Zinc

Laboratory tests carried out by Sprague (40a) in water with a total hardness of 14 mg/l as $CaCO_3$* at 17°C demonstrated that the incipient lethal levels** or threshold concentrations of copper and zinc sulfate solutions for juvenile Atlantic Salmon were 0.032 mg/l of copper alone, or 0.42 mg/l of zinc alone. The incipient lethal level for mixtures of zinc and copper are half of the above concentrations. Similar results have been obtained for rainbow trout (Figure 5).

In a ten-year study Saunders and Sprague (40b) analyzed avoidance reactions of spawning migrations of Atlantic Salmon to copper and zinc pollution from mining operations in the Northwest Mirimachi River in

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* Atlantic Salmon of North America are typically found in very soft water with a total hardness less than 20 ppm.

** Incipient lethal level, or lethal threshold concentration, is that level of the lethal identity beyond which the organism can no longer survive for an indefinite period of time.

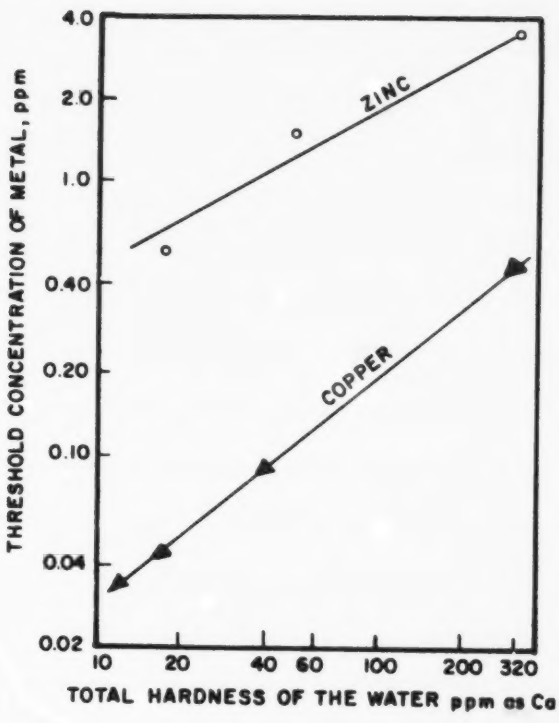

FIGURE 5. Relation between the hardness of the water and the threshold concentrations of zinc, and copper salts for rainbow trout. Taken from Lloyd (41).

Canada. These observations are pertinent since they took place in the natural environment without the usual limitations inherent in laboratory experimental conditions. The authors expressed the pollution levels of copper and zinc in terms of "toxic units". The toxic unit can be expressed as the concentration of the pollutant actually found, divided by the lethal threshold concentration obtained from laboratory experiments. A toxic unit of 0.5 would be half as strong as the lethal threshold concentration and a toxic unit of 2 would be twice as strong as the lethal threshold level.

During the first six years of study which preceded the mining pollution, a 1% to 3% downstream return of salmon was recorded, while in the four years following the beginning of the copper and zinc pollution, a 10% to 22% downstream return of migrating salmon occurred. Avoidance reactions of adult Atlantic Salmon occurred at about 0.35 to 0.43 toxic units of $Cu^{2+} + Zn^{2+}$. A level of 0.8 toxic unit may cause a total block to migration. Of the salmon returning downstream because of pollution, about 31% reascended, 7% were taken by fishing and 62% were not seen again. Estimated losses of the total salmon run were as high as 15%. Another interesting result that occurred after the mining pollution began was a delay and reduction of early run salmon (June-July) to the headwaters.

Levels of Pesticides for Certain Salmonoids

With the exception of a few insecticides, there have been few research efforts to determine the effect of pesticides on Atlantic Salmon. Laboratory research, however, has been performed with other salmonoids. Table 4 records median tolerance limits (TLm)* of three salmonoids to various pesticides. Because the values in Table 4 do not indicate maximum safe levels, concentrations of materials that are nonpersistent (half life of less than 96 hours) or have nonculmulative effects after mixing with receiving waters should not exceed 1/10 of the 96 hour TLm value at any time or place. The 24-hour average of the concentration of such substances should not exceed 1/20 of the TLm value after mixing. For other toxicants, concentrations should not exceed 1/20 of the 96-hour TLm value at any time or place and the 24-hour average of the concentration of these materials should not exceed 1/100 of the 96-hour TLm after mixing. This level was established in 1968 by the National Technical Advisory Committee (4). Due to existing stream conditions**, the suggested safe levels of toxicants may prove to be inadequate in some cases. For a more complete review of pesticides and their effects upon fish life, the reader may wish to refer to McKee and Wolfe's study entitled Water Quality Criteria (42) and the Report of the Committee on Water Quality Criteria (4).

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* Median tolerance limit (TLm) - The concentration of the tested material in experimental water at which just 50 percent of the test animals are able to survive for a specified time of exposure.

** High water temperature or low dissolved oxygen concentration generally increase the action of toxicants.

TABLE 4

MEDIAN TOLERANCE LIMITS OF VARIOUS TOXICANTS IN PARTS PER MILLION FOR 3 SALMONOIDS (FROM KATZ 43; BOND 44)

Commercial Common or Code Name of Toxicant	MEDIAN TOLERANCE LIMITS IN PARTS PER MILLION											
	Chinook Salmon				Coho Salmon				Rainbow Trout			
	24 hr.	48 hr.	72 hr.	96 hr.	24 hr.	48 hr.	72 hr.	96 hr.	24 hr.	48 hr.	72 hr.	96 hr.
Toxaphene	.0079	.0033	.0027	.0025	.013	.0105	.010	.0094	.0115	.0084	.0084	.0084
Aldrin	.0124	.0106	.0087	.0075	-	.061	.0486	.0459	.0424	.0239	.0203	.0177
Dieldrin	.0079	.0067	.0061	.0061	.0175	.0153	.0144	.0108	.0157	.013	.0099	.0099
DDT	.038	.017	.014	.0115	.066	.046	.044	.044	.042	.042	.042	.042
Lindane	.056	.042	.042	.040	.060	.056	.056	.050	.042	.041	.039	.038
Methoxychlor	.028	.0279	.0279	.0279	.0662	.0662	.0662	.0662	.0626	.0626	.0626	.0626
Heptachlor	.0324	.0266	.023	.0173	.0619	.0604	.0604	.059	.0367	.0338	.0251	.0194
Chlordane	.059	.059	.057	.057	.1	.086	.082	.056	.056	.044	.044	.044
Endrin	.002	.0012	.0012	.0012	.0013	.0008	.00052	.00051	.00079	.00058	.00058	.00058
Guthion	.0068	.0062	.0043	.0043	.007	.005	.0048	.0042	.0047	.0038	.0038	.0032
Malathion	.0245	.0239	.0236	.023	-	-	-	-	-	-	-	-
Co-Ral	-	-	-	-	22	20	18	15	-	1.8	1.5	1.5
Sevin	-	-	-	-	1.3	.997	.997	.997	-	1.6	1.35	1.35
ACP-M-569	185	155	-	-	-	-	-	-	Data Not Available			
Aminotrizaole	-	-	-	-	325	325	-	-	"	"	"	
Baron	2.62	2.3	-	-	-	-	-	-	"	"	"	
Dowpon	-	-	-	-	340	340	-	-	"	"	"	
Diquat	29.5	28.5	-	-	-	-	-	-	"	"	"	
Diuron	-	-	-	-	33	16	-	-	"	"	"	
Endothal	155	136	-	-	-	-	-	-	"	"	"	
F-98	.08	-	-	-	-	-	-	-	"	"	"	
Hyamine 1622	-	-	-	-	57	53	-	-	"	"	"	
Kuron	1.35	1.23	-	-	-	-	-	-	"	"	"	
Monuron	-	-	-	-	115	110	-	-	"	"	"	
Omazene	.83	.83	-	-	-	-	-	-	"	"	"	
Phygon XL	-	-	-	-	Not toxic up to .042			-	"	"	"	
Simazine	7.0	6.6	-	-	-	-	-	-	"	"	"	
Sodium TCA	Not toxic up to 870		-	-	-	-	-	-	"	"	"	

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VII. APPENDIX A

Life Cycle

Atlantic Salmon are an anadromous species which ascend cool fresh-water rivers in order to spawn. Spawning grounds include the waters extending from just above tidal areas to headwater reaches. Spawning occurs in the fall, and the eggs hatch in the late winter or early spring. The newly-hatched salmon live in fresh water two or more years before they migrate to the sea. Here, the salmon remain for at least one year before they return to fresh water and spawning areas. After spawning, some adult salmon immediately make their way back to sea while others remain in fresh water the whole winter before returning the following spring. Because of the great energy expended during the physiological preparations of reproductive organs and spawning itself, many of the salmon which return to sea after spawning are so weak that they fall easy victims to predation and disease.

The time at which salmon migrate to spawning grounds varies with different streams. Many rivers have distinct runs both in spring and fall; while in others, the migrations are limited to one peak run occurring either during the spring or fall. Regardless of when migration occurs, Atlantic Salmon spawn in late October or early November in North America when the water temperatures drop to 5.6 - 4.4^{o}C (23).

Female salmon deposit their eggs in gravel beds (redds) and cover them to average depth of ten inches. Shallow, swift-running water areas

with clean coarse gravel beds that contain many stones from 2 to 8 inches in size provide the most suitable spawning areas for Atlantic Salmon(45). This type of stream bed produces a stable environment and affords the buried eggs a constant supply of oxygenated water. Fine or loose gravel and sand is unsuitable because of its shifting nature and low porosity. Water depth of spawning areas, varying from 6 - 48 inches is also important and must be sufficient to protect the spawning areas from ice and freezing (45).

The incubation of the eggs lasts about 5 - 6 months depending upon temperature. The eggs will hatch in early spring when the temperatures are just beginning to rise. The newborn salmon are termed alevins or sac-fry and are so called because they hatch with their yolk-sac still attached. Once the yolk-sac is nearly absorbed, the fry or underyearlings make their way out of the over-lying gravel and begin to feed on their own.

The duration of the fresh water phase of the salmon's life cycle is usually not longer than two or three years, and it is passed in the same general area from which the salmon hatched. Juvenile salmon, termed parr, inhabit riffles and pools which contain large protective rocks under which they hide when alarmed (45; 46). The parr are characterized by eleven black bars or "parr Marks" running vertically down the sides and by bright red spots arranged near the lateral line. Before migration to the sea, the parr undergo a process called smoltification. When the parr reach a length of about five inches, the following

spring, they lose their coloration and turn silvery on the outside. After this physiological change in preparation for life in salt water, the fish, termed smolts, are ready for their seaward migration. Smolts migrate in spring or early summer when the water temperatures are cool.

At sea, the young salmon grow rapidly on the abundant food supply and usually gain an average of 4 - 5 pounds a year (27). Although some salmon return to fresh water after spending only one winter at sea, most Maine salmon remain two winters at sea before returning to spawn. The salmon that return to fresh water after one winter are termed grilse while those that return after two winters are termed bright or maiden salmon.

Subsequent to entering fresh water, Atlantic Salmon cease feeding and expend great amounts of energy in the ascension of rivers, and in the transformation of body material for the build-up of the reproductive organs. Large amounts of energy are also expended during actual spawning. Without feeding, such activity causes an excess drain upon the salmon's reserve energy materials which results in a 31 to 40 percent loss of body weight. Consequently, the salmon are very close to physiological death (45). Thus after spawning, the salmon return to sea in an excessively weak condition. Such salmon are incapable of osmoregulation and are easy victims of predators and disease. Only 10% or less of the salmon return to spawn a second time.

VIII. APPENDIX B

STATEMENT OF INTENT
FOR
A COOPERATIVE FISHERY RESTORATION PROGRAM
FOR THE
CONNECTICUT RIVER BASIN

The States of Connecticut, Massachusetts, New Hampshire and Vermont as well as the United States Bureau of Sport Fisheries and Wildlife and the United States Bureau of Commercial Fisheries agree to and support a fisheries program for the Connecticut River Basin. The following statement shall constitute the official intent of the above-named States and Federal Agencies.

Objectives

The objectives of this program are to realize the full potential of the fishery resources of the River including both anadromous and resident species. The intent of this program is to provide a public with high quality sport fishing opportunities in a highly urbanized area as well as to provide for the long term needs of the population for sea food.

Anadromous Fish

American Shad - *Alosa sapidissima* - Historically, the Connecticut River supported shad runs as far unstream as Bellows Falls which lies in the River between Vermont and New Hampshire, approximately 35 miles north of the Massachusetts border. The exact magnitude of the historic run is unknown but it might have approached six million adult fish

at the mouth of the River. It probably would not be practical to restore the run to its historical numbers but an evaluation of present spawning and nursery areas as far north as Bellows Falls indicates that a run of up to two million fish could be realized. The two million figure is based on the production of 2.8 adult shad produced per 100 square yard unit of spawning habitat. The 2.8 figure assumes rather low production, as production as high as 6.5 adult shad per unit has been realized.

A run of two million shad would require passage facilities for one million fish at Holyoke, 850,000 at Turners Falls, and 750,000 at Vernon. If the navigation dam under consideration by the Corps of Engineers is constructed at Hartford, Connecticut, facilities would have to be provided for a run of two million shad. In addition to sustaining the run, the passage facilities should provide an annual harvest of 100,000 shad above Hartford, 50,000 shad above Holyoke, 42,500 above Turners Falls, and 37,500 above Vernon.

Atlantic Salmon - Salmo salar - The magnitude of the original salmon run in the Connecticut River is unknown, although there are many historical references that indicate that the run was sizeable and originally went as far as Beecher Falls near the Canadian Border. Utilizing a unit area technique similar to that used with shad and evaluating the River as far as the Cummerford Dam, reveals a potential run of adult salmon at the River's mouth of 38,000.

This figure is based on the production of three smolts per unit area

with a survival to maturity of five percent. A realistic approach to natural production of salmon indicates that man-made changes in the tributaries prevent the actual attainment of a natural run of 38,000 fish. However, there is no reason why the 38,000 figure cannot be realized or exceeded through a smolt stocking program.

The problem of salmon passage on the main stem does not require lengthy discussion as facilities adequate for the anticipated large shad runs will readily pass the number of salmon involved.

Other Anadromous Species - Various other species occur in the River that will benefit from a program designed to develop shad and salmon fisheries. The only species that probably would use passage facilities to a large degree is the blueback herring, Alosa aestivalis. If a commercial fishery can be developed for this herring, passage facilities would have an additional benefit.

Resident Species - In addition to establishing and maintaining runs of anadromous fishes, we also intend to maintain and enhance various resident species found throughout the basin.

Benefits - It is always difficult when dealing with a resource that is not entirely commercial to establish the value of said resource. Nevertheless, an attempt has been made although it should be realized that the value, for example, of an angler-caught Atlantic Salmon from the Connecticut River is probably far beyond anything that we could establish with simple dollars and cents.

Some data is available on the value of resident species, but more information is required and overall fishery values for the River will be subject of a later report.

Information indicates that the present average annual retail value of the shad commercial fishery is approximately $150,000. If economics and the market permitted, it appears that this annual value could be doubled with the increased predicted runs.

The present shad sport fishery has an annual value of $150,000 based on 50,000 angler days. Predicted catches based on a run of 2,000,000 fish indicate a sport's harvest of 100,000 fish in Connecticut; 50,000 from Holyoke to Turners Falls; 42,500 from Turners Falls to Vernon and 37,500 above Vernon. Based on current fisherman day value of $3.00 and one fish per man per day, the predicted annual additional value gained from proper management would amount to $537,000.

A run of 38,000 salmon should produce a catch of 9,600 fish based on a 25 percent harvest. Considering the extreme pressure that might be generated by a salmon run in the Connecticut River, this figure may be low. Using the current figure of $120,[redacted] per angler caught salmon, the annual value would amount to $1,152,000. The potential combined annual value for new shad and salmon sport fisheries amounts to $1,689,000.

Problems and Needs - To attain the objectives that have been discussed, many problems must be surmounted and much work must be done.

The water quality of the River must be maintained and improved. All of the Connecticut River States are now active in classifying their waters as to water quality and it appears that the standards to be set will be suitable for shad and salmon. The threat of thermal pollution is a very real one with one nuclear plant shortly going into operation in Connecticut and another one proposed at Vernon, Vermont. The Connecticut Yankee Atomic Power Company, as a condition of their construction permit, is presently supporting a study to determine the effects of their heated discharge water on shad. We need more information regarding thermal pollution tolerance and effects on salmon and this type of work will be outlined in the Research Plan to be drawn up by the Technical Committee for Fisheries Management of the Connecticut River Basin. Although subject to future research finding, it appears that any increase in the water temperature at Vernon could seriously hinder salmon and shad restoration in the upper basin.

The Corps of Engineers is considering the construction of a dam at Hartford for navigational purposes. The dam will create fish passage problems and perhaps more important, eliminate fishing sites and excellent shad spawning areas. We must oppose the construction of this dam because it would be inconsistent with the aims of the fishery restoration program.

Based on the present fragmentary data available on the Northfield Pump Storage Project, it appears that this project poses definite limitations to an anadromous fish restoration program. These limitations

involve the physical loss of eggs, larvae and young fish of both anadromous and resident species, and an orientation problem for both upstream and downstream migrants attributed to pumping large volumes of water. Studies designed to minimize the potential adverse effects to fishery resources should be undertaken in development of the design for the Northfield Pump Storage Project. In related studies, fish screens, barriers and deflectors and flow regimen must be thoroughly investigated.

If the runs outlined are to become a reality, there are also major problems to be solved for the passage of both upstream and downstream migrants over existing dams. Larger runs may require modification of the Enfield Dam; facilities must be developed by Holyoke, Turners Falls and Vernon for shad and a fishway for salmon will be required at Bellows Falls. There are many unsolved problems concerning fish passage facilities particularly with regard to shad. Members of the Technical Committee have made a start on these problems and a full-fledged research project will be forthcoming in the near future. Considerable work must be done on the various tributaries to evaluate fish passage needs.

Lack of low flow augmentation is another problem, and the Technical Committee proposes to develop these needs and to work with the Corps of Engineers and private companies to solve this situation.

A thorough review must be made of the many proposals to build multi-purpose dams in the basin; particularly with regard to their effects on the fishery restoration program.

When the proposed fisheries become a reality, the four States involved will cooperate to establish regulations that will maintain the fisheries as well as assure that each State receives its just share of the fishery harvest.

There is presently a need for fishermen access sites on the River and the need will greatly increase as the program progresses. Connecticut and Massachusetts have already made progress in providing access and all of the States will develop a large scale program in the near future.

We endorse and support the Technical Committee for Fisheries Management of the Connecticut River Basin as the group designated to design and implement needed research programs as well as to develop and recommend sound fishery management procedures. The Committee shall consist of representatives from the Connecticut Board of Fisheries and Game, the Massachusetts Division of Fisheries and Game, the Massachusetts Division of Marine Fisheries, the New Hampshire Fish and Game Department, the Vermont Fish and Game Department, the United States Bureau of Sport Fisheries and Wildlife and the United States Bureau of Commercial Fisheries.

April 20, 1967

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